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## THE SUPERSYMMETRY SCHEME AND E2 TRANSITION RATES IN THE Pt REGION

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Elastic and inelastic proton scattering from <sup>191</sup>Ir, <sup>193</sup>Ir and <sup>194</sup>Pt have been studied at  $E_p = 50$  MeV. The E2 reduced transition rates obtained for the low-lying states in these nuclei agree qualitatively with the predictions of the supersymmetry scheme recently proposed for these nuclei.

Recently, it has been suggested [1] that dynamical supersymmetries may be present in the spectra of complex nuclei. This suggestion was based on the analysis of the excitation energies of a pair of nuclei, <sup>192</sup>Pt and <sup>191</sup>Ir, which could be fitted simultaneously by the same energy formula. One of the new aspects of the supersymmetry scheme, which resulted from a coupling of a  $j = 3/2$  particle to an O(6) core, is that both even and odd nuclei are described at the same time. If a supersymmetric scheme is appropriate in this region of nuclei, then other properties should also be describable within that scheme. Of particular importance are  $B(E2)$  values. Although experimental transition rates were previously known in this mass region [2,3] they might have suffered from normalization problems, since they had been obtained in different experiments. We have thus performed a new (p, p') experiment in which the  $B(E2)$  values are measured simultaneously both in the even (<sup>194</sup>Pt) and in the odd (<sup>191</sup>Ir and <sup>193</sup>Ir) nuclei. Although other, more complicated, calculations may also predict  $B(E2)$  values in this mass region, we have confined our attention to a test of the supersymmetry scheme. The supersymmetry scheme predicts strong excitation of the  $2_1^+$  states in the even- $A$  Pt nuclei and of the  $1/2_1^+$ ,  $5/2_1^+$  and  $7/2_1^+$  states of the odd- $A$  Ir isotopes. The predicted E2 transition rates [4] depend only on the number of bosons

and some Clebsch–Gordan coefficients. These are given for even and odd nuclei by analytic expressions:

$$B(E2; \tau + 1 \rightarrow \tau) = \alpha \frac{\tau + 1}{2\tau + 5} (N - \tau)(N + \tau + 4),$$

for even nuclei ,

$$B(E2; \tau + 1 \rightarrow \tau) = \alpha \frac{\tau + \frac{1}{2}}{2\tau + 4} (N - \tau + \frac{1}{2})(N + \tau + \frac{9}{2}),$$

for odd nuclei ,

where  $N$  is boson number and  $\tau$  is a quantum number which characterizes the irreducible representations of Spin(5);  $\alpha$  is an overall normalization factor. For comparison, a weak-coupling model [5] would predict identical  $B(E2\downarrow)$  values for these states in Ir, and also the same  $B(E2\downarrow)$  values for the transition from the  $3/2_2^+$  state to the  $3/2_1^+$  ground state of <sup>191</sup>Ir and <sup>193</sup>Ir, which is forbidden in the supersymmetry scheme. Our conclusions are that E2 transition rates obtained from inelastic proton scattering on <sup>191,193</sup>Ir and <sup>194</sup>Pt are in qualitative agreement with the supersymmetry predictions and hence give further evidence for its presence in the Pt region.

The experiments were performed in one run using the same experimental set-up. A 50 MeV analysed proton beam from the KVI cyclotron was used to bombard self-supporting targets of <sup>191</sup>Ir, <sup>193</sup>Ir and <sup>194</sup>Pt with thicknesses of 200, 150 and 200  $\mu\text{g}/\text{cm}^2$ , respectively. Scattered protons were detected using the QMG/2 magnetic spectrograph [6] and its focal plane

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detection system [7]. The protons were identified by their time of flight and energy loss signals.

The solid angle subtended by the spectrograph was 1.82 msr, with an opening angle in the reaction plane of  $1^\circ$ . The overall energy resolution varied between 22 and 27 keV. This was good enough to resolve the transitions of interest except for a few cases. This is illustrated in fig. 1, where spectra taken at  $\theta_{\text{lab}} = 51^\circ$  for  $^{191}\text{Ir}$ ,  $^{193}\text{Ir}$  and  $^{194}\text{Pt}$  are displayed. In  $^{194}\text{Pt}$  all transitions below  $E_x = 1.0$  MeV are completely resolved. In  $^{193}\text{Ir}$ , the transition to  $E_x \approx 75$  keV could be due to excitation of the  $1/2^+$  state at  $E_x = 73$  keV and the  $11/2^-$  state at  $E_x = 80$  keV. However, the  $11/2^-$  state is expected to be very weakly excited by an  $L = 5$  transition. This is obviously the case for the  $11/2^-$  state in  $^{191}\text{Ir}$  at  $E_x = 171$  keV. Although this state was not resolved from a  $3/2^+$  state at 179 keV, both states are observed to be excited weakly. A more troublesome case is the transition to  $E_x \approx 358$  keV in  $^{193}\text{Ir}$  which can include contributions from  $L = 2$  transitions to a  $7/2^+$  state at 358 keV and a  $(5/2^+)$  state at 362 keV. A similar situation occurs for the transition to  $E_x \approx 343$  keV in  $^{191}\text{Ir}$  which may have contributions from  $L = 2$  transitions to a  $7/2^+$  state at  $E_x = 343$  keV and a  $5/2^+$  state at  $E_x = 351$  keV. While these  $7/2_1^+$  states in  $^{191,193}\text{Ir}$  are strongly observed [2] in Coulomb excitation measurements, the  $5/2_2^+$  states are observed [2] to be *very weakly* excited. We expect the same to be true in  $(p, p')$  measurements.

Angular distributions were measured between  $\theta_{\text{lab}} = 15^\circ$  and  $\theta_{\text{lab}} = 51^\circ$  in steps of  $3^\circ$ . At the very forward angles the tail of the strong elastic peak made the analysis of the very low-lying states impossible. Besides, at some of the forward angles, strong peaks from  $^{12}\text{C}$ ,  $^{16}\text{O}$  and other contaminants indicated in fig. 1 overshadowed some of the low-lying transitions. In the case of the  $1/2^+$  state at 73 keV in  $^{193}\text{Ir}$ , we were not able to obtain a cross section at any of the angles because of the above mentioned reasons. However, we could estimate at some angles that this state has a cross section smaller than  $1/6$  of the cross section for the  $5/2$  state at 139 keV.

The shapes of the angular distributions for the elastic scattering from all three targets agree in minute details over the whole measured angular range. The inter-normalization of the data with respect to the elastic cross sections yields inelastic cross sections for the three targets with errors less than 5%. To get absolute

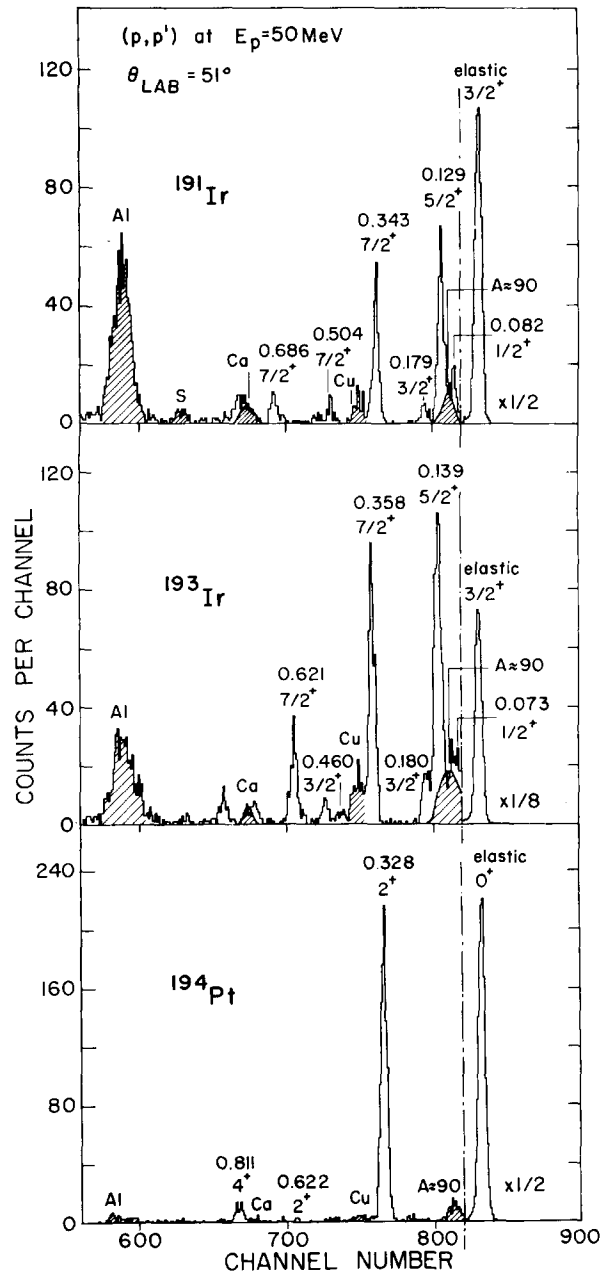


Fig. 1. Spectra for 50 MeV proton scattering from  $^{194}\text{Pt}$  and  $^{193,191}\text{Ir}$  taken at  $\theta_{\text{lab}} = 51^\circ$ . The low-lying transitions studied in this paper are indicated. Hatched areas correspond to contaminant peaks.

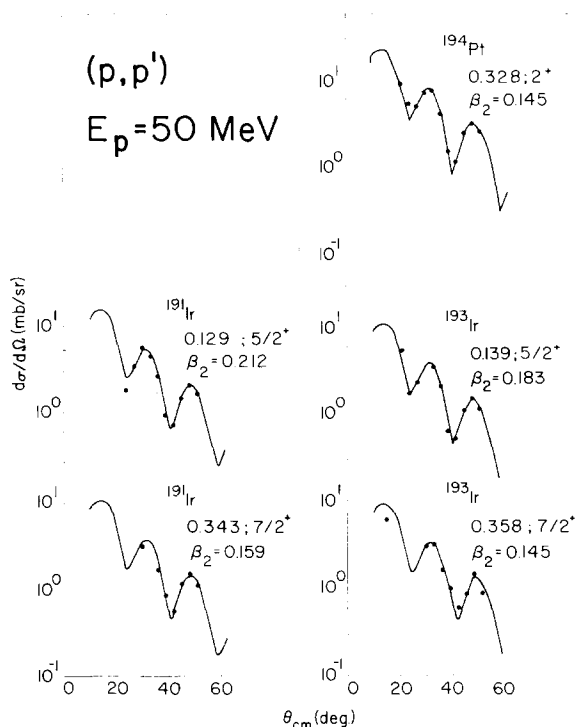


Fig. 2. Differential cross sections obtained for the strong  $L = 2$  transitions in  $^{194}\text{Pt}$  and  $^{193,191}\text{Ir}$ , labeled with excitation energy (in MeV) and  $J^\pi$ . Errors, where greater than the data symbols, are indicated. The curves through the data are results of DWBA calculations with  $L = 2$  collective form factor. Deduced coupling strength parameters  $\beta$  are indicated.

cross sections we normalized our elastic data to the results of an optical model calculation with parameters taken from table 1-(ii) of ref. [8] as were obtained for 51 MeV proton scattering from  $^{152}\text{Sm}$ . The same normalization factor was then used to obtain absolute cross sections for inelastic scattering. We estimate that by using this normalization procedure the overall experimental uncertainties on the absolute cross sections are less than 10%. Inelastic cross sections for the strong transitions are shown in fig. 2. Already from inspection of the spectra in fig. 1 it becomes apparent that only those states predicted [4] by the supersymmetry scheme to have E2 transitions to the ground states are excited with any appreciable strength except perhaps for the lowest  $1/2^+$  states in  $^{191,193}\text{Ir}$ . All other states which could be reached by  $L = 2$  transitions are very weakly excited. Relative  $B(E2)$  values were obtained from comparison of the data of the various  $L = 2$  transitions

with each other and with DWBA calculations in which a collective form factor was used. To check the implicit assumption that coupled channel (CC) effects do not contribute to the inelastic cross sections a number of CC calculations was made. These gave differential cross sections for the strong states which differed very little from the DWBA results. The DWBA predictions (fig. 2) fit the measured data rather well for all observed  $L = 2$  transitions, except for the weak  $2_2^+$  state in  $^{194}\text{Pt}$  where the data (not shown) seem to be out of phase with the calculations indicating CC effects.

In table 1 we summarize the results of our analysis. The presented relative  $B(E2)$  values are normalized so that in each column the  $B(E2)$  value of the  $0^+ \rightarrow 2_1^+$  transition in  $^{194}\text{Pt}$  is equal to unity. In column 4 the  $B(E2)$  values obtained from our experiment are listed. For the strong  $L = 2$  transitions these normalized  $B(E2)$  values have relative errors smaller than a few percent. These are to be compared with the  $B(E2)$  values predicted [4] by the supersymmetry scheme listed in column 5. In general predicted strong E2 transitions are observed strongly in our experiment. For both lowest  $5/2^+$  states, however, the supersymmetry scheme seems to underestimate the experimental values by about a factor 1.5 while for the  $1/2_1^+$  states it overestimates them by a factor of 2–3. For the  $7/2_1^+$  states, on the other hand, there is excellent agreement. We also note the reproduction of the trend of the E2 transition rates in going from  $^{193}\text{Ir}$  to  $^{191}\text{Ir}$  which differ by one boson.

The lowest excited  $3/2^+$  states are populated only very weakly, in agreement with the predictions of the supersymmetry scheme. Moreover, the E2 transition rates for these states are smaller by a factor of 3–3.5 than those predicted by the vibrational and weak-coupling models [5].

That the  $B(E2)$  values for the lowest  $1/2_1^+$  and  $5/2_1^+$  states are not very well reproduced might be not so surprising. While the supersymmetry scheme predicts more or less a degenerate triplet  $1/2_1$ ,  $5/2_1$  and  $7/2_1$  [1], it is experimentally seen that the  $1/2_1$  and  $5/2_1$  states are pushed down in energy as compared to the  $7/2_1$  state. The same perturbation that produces these shifts in energy, which could be partly due to the near-by presence of the  $3s_{1/2}$  and  $2d_{5/2}$  orbits, might also affect the E2 transition rates.

$B(E2)$  values obtained from Coulomb excitation measurements [2,3] are listed in column 6. In general, there is good agreement with our data, except for the

Table 1

Relative  $B(E2)$  values normalized to the  $B(E2, 0_1^+ \rightarrow 2_1^+)$  in  $^{194}\text{Pt}$ , compared with transition rates predicted by the supersymmetry scheme and with results from Coulomb excitation measurements.

Nucleus	$E_x^a)$ (keV)	$J\pi^a)$	$B(E2^\dagger)$ (this work)	$B(E2^\dagger)^b)$ (theory)	$B(E2^\dagger)^a)$ (Coul. ex.)
$^{194}\text{Pt}$	328.5	$2_1^+$	1.00	1.00	1.00 <sup>c)</sup>
	622.0	$2_2^+$	—	0.00	0.005 <sup>f)</sup>
$^{193}\text{Ir}$	73.0	$1/2_1^+$	$\leq 0.08$	0.11	$0.068 \pm 0.007$
	139.0	$5/2_1^+$	0.48	0.33	$0.44 \pm 0.03$
	180.0	$3/2_2^+$	0.07	0.00	$0.052 \pm 0.006$
	358.0	$7/2_1^+$	0.40	0.44	$0.30 \pm 0.03$
	361.8	$(5/2)_2^+ d)$	0.00	0.00	$0.008 \pm 0.001$
	460.5	$3/2_3^+$	0.019	0.00	$0.017 \pm 0.002$
	621.0	$7/2_2^+$	0.10	0.00	$0.056 \pm 0.007$
$^{191}\text{Ir}$	82.4	$1/2_1^+$	0.04	0.14	$0.051 \pm 0.006$
	129.4	$5/2_1^+$	0.64	0.41	$0.55 \pm 0.04$
	178.9	$3/2_2^+$	0.08	0.00	$0.068 \pm 0.006$
	343.2	$7/2_1^+$	0.48	0.54	$0.31 \pm 0.03$
	351.2	$5/2_2^+ e)$	0.00	0.00	$0.017 \pm 0.003$
	504.0	$7/2_2^+ e)$	0.07	0.00	—
	686.3	$7/2_3^+ e)$	0.08	0.00	$0.058 \pm 0.007$

a) Ref. [2], except if noted otherwise. b) Ref. [4].

c)  $B(E2)$  value obtained from Coulomb excitation for  $0^+ \rightarrow 2^+$  transition in  $^{194}\text{Pt}$  [3]. All Coulomb excitation  $B(E2)$  values were normalized to this value.

d) Ref. [9]. e) Ref. [10]. f) Ref. [3].

$7/2_1^+$  states in  $^{191}\text{Ir}$  and  $^{193}\text{Ir}$  at  $E_x \approx 343$  and 358 keV, respectively, where the two measurements disagree. This disagreement persists even if we assume for the  $5/2_2^+$  states twice the  $B(E2)$  values as observed in Coulomb excitation. Our  $B(E2)$  values for the  $7/2_1^+$  states are in closer agreement with the supersymmetry predictions and also show the correct trend with increasing boson number.

In conclusion, deduced E2 transition rates for  $^{191}\text{Ir}$ ,  $^{193}\text{Ir}$  and  $^{194}\text{Pt}$  are in qualitative agreement with the predictions [4] of the supersymmetry scheme proposed by Iachello [1]. In that respect, these results support this scheme for the nuclei in the Pt region.

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